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INITIATIVES AND FACILITIES FOR E&T IN THE NUCLEAR SCIENCE AND TECHNOLOGY MASTER AT UPM

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1. Introduction

The present Master/Doctorate in Nuclear Science and Technology programme implemented in the Department of Nuclear Engineering of the Universidad Politécnica de Madrid (NED-UPM) has the excellence qualification by the Spanish Ministry of Education. One of the main objectives of this programme is the training for the development of methodologies of simulation, design and advanced analysis, including experimental tools, necessary in research and in professional work in the nuclear field. This is, Fission and Fusion Reactors, including fuel cycle, waste management and safety aspects, and also non-energy uses of nuclear physics and technologies. The programme includes other basic disciplinary contents such as Quantum Mechanics and Atomic & Nuclear Physics, Non-Energy uses of Radiation Sources (such as Lasers and Accelerators) as well as, Nanotechnology.

In this context, based on the experience gained through research, significant efforts have been done to improve the following subjects in the curricula: Nuclear Power Plants (NPP), Nuclear Technology, Nuclear Safety, Nuclear Reactor Design, Radiation Sources for Diagnosis, Medical, Industrial Application, and Quantum Mechanics Applications such as nanoscience and Nanotechnology.

But more realistic studies are also required to complete the education & training objectives in the “Nuclear Safety” and “Nuclear Power Plants” programmes. For this purpose, we use a full scope Interactive Graphical Simulator (IGS) running in real-time, which was donated by the Spanish José Cabrera NPP, after its operation ceased in 2006. The simulator was used during the commercial exploitation of the plant for training of the main control room personnel, technical support engineers, and for operations management. It was commissioned in NED-UPM in 2008.

On the experimental side, NED-UPM has a neutron measurements laboratory with a calibration bench, and presently a new facility based on sputtering techniques is being commissioned in order to support training and research on development and testing of new high radiation-resistant materials.

2. Codes and experiments for design and advanced analysis in Nuclear Engineering.

The experience gained in the last years by NED-UPM in the development of Codes for design and advanced analysis in Reactor Physics has been included in the Master Programme, with the understanding of the current computational methodologies/codes from the nuclear data processing, the lattice and core calculations codes, the 3D Core Physics simulations at static and dynamic conditions, and finally the power plant simulators.

A large experience in Plasma Physics and Advanced Materials development, characterization and testing under irradiation, together with Reactor Systems for Nuclear Fusion, is also incorporated in the Programme. This includes the development of codes for High Energy Density Matter studies, which is key for inertial fusion energy (both Radiation Hydrodynamics and Atomic Physics), but also original codes in atomic quantum and classical dynamics and defects diffusion for Materials Research in a scheme of multiscale simulation, with new developments in Fluid dynamics and Basic Physics for Liquid Metals behaviour, important in new generation of Fission and Fusion Reactors, and accessibility to experimental facilities for the students.

The “Nuclear Reactor Design” programme has been focused on the understanding of the computational codes for nuclear reactor design, starting with the nuclear data processing codes, the core calculations codes, and finally the plant simulators codes (JANIS, NJOY, WIMSD, ORIGEN/ACAB, MCNP, COBAYA/SIMULA, COBRA, SIMTRAN, RELAP).

Some of these codes have been developed in our NED-UPM for many years including the generation of the necessary cross-section libraries for accurate use of the codes. First, visualizing with JANIS code, and checking nuclear data from Evaluated Nuclear Data Files (ENDF), with ENDF Utility Codes. Different lattice codes have been developed to solve the neutron transport equation to model pin-cells and clusters taking part of the SEANAP system developed by NED-UPM for NPP design. Deterministic computational methods are complemented with Monte Carlo calculations. Students are introduced in this methodology and several examples for shielding and criticality systems are simulated with MCNP4.

For activation and burn-up calculations ACAB and ORIGEN2.2 codes are used. ACAB code (partially developed by NED-UPM) is designed to perform activation and transmutation calculations for nuclear applications. ACAB is used to simulate realistic operational scenarios of very different nuclear systems: inertial fusion, magnetic fusion, accelerator driven systems, and fission reactors.

Neutronic calculations for core design in 2D and 3D are introduced with COBAYA and SIMULA codes, respectively. These codes also are part of SEANAP system. For core design and operational monitoring we use our SIMTRAN code, SIMTRAN is a 3D-PWR core dynamics code, under development and validation for 20 years. It was developed as a single code merge, with data sharing through the 3D neutron-kinetics nodal code (SIMULA) and the multichannel, with cross flows, thermal-hydraulics code COBRA IIIC/MIT2. COBAYA3 is also now integrated in the NURESIM European platform for best-estimate reactors simulation.

For Multiscale Simulation of Materials, a significant number of developments have been performed with original development or co-development of Molecular Dynamics codes such as MDCASK, and Kinetic MonteCarlo (modified BIGMAC). In general, the full scale is covered from First Principles (SIESTA, VASP), Molecular Dynamics (MDCASK and LAMMPS), Defects Diffusion by MonteCarlo, Dislocation Dynamics, and Structural Codes such as ANSYS, but also with a large modification and adaptation to our problems of free codes such as CODEASTER.

Fluid dynamics problems in nuclear facilities (both reactors or research in New Sources) is covered by implementing and using popular CFD codes such as ANSYS-FLUENT or STAR-CD, extensively modified in some cases for specific problems. In particular, a large modification includes new data generated by using Quantum and Classical Molecular Dynamics, to study liquid metals such as LiPb or others, and get responses to problems of heat transport, corrosion or phase transition. Safety aspects for new Nuclear Systems are considered by using a special version of the MELCOR code for liquid metals, which is being implemented. Also in the safety area, and for fusion reactors, the diffusion and transport of tritium inventory has been originally implemented with new data in codes such as TMAP in order to estimate the final T inventory.

A key aspect developed is the computational coupling of those codes; from the 3D CAD/CAM description of the system to be studied, the particle transport, the heat deposition and particle irradiation, the generation of the basic numbers of material damage and activation, the fluid dynamics of the heat extraction (coolant), the tritium breeding in case of fusion, and the thermo-mechanical effects up to the Power Plant Thermodynamics cycle.

Atmospheric dispersion of radioactive elements in case of accidents are modelled with available codes but also with some new including new chemistry and physics such as Tritium analysis. A new battery of data has been included for components different of HTO, HT and organic bound tritium (OBT), with new models in NORMTRI, UFOTRI and the weather ECMWF/FLEXPART dispersion model, to incorporate the sequential chain of elements after deposition and through the organic systems with evaluation to the environment.

3. Facilities

3.1 Interactive Graphical Simulator

NED-UPM was provided in 2008 with the *Interactive Graphical Simulator* of the PWR nuclear power plant “José Cabrera”, whose operation ceased definitively in 2006. The simulator is a state-of-the-art full-scope real-time simulator, which was used for training and qualification of the plant operators. The Simulator plays an important role for education and training of our students, providing an attractive virtual space that allows to improve the understanding of the whole plant components and its safety systems. The *Consejo de Seguridad Nuclear* grants each course several fellowships for training of students in this installation.

The Interactive Graphical Simulator is a full scope PWR nuclear Power plant engineering simulator that is especially useful for didactic purposes, as it is an interactive tool that allows the student to complete the teaching-learning methodology in nuclear science and technology as is recommended in the new engineering studies adapted to the Bologna rules. This simulator attracts, motivates and retains students within the nuclear science, and improves the quality of training, making students more active in their own learning and replacing simple memorization of the complex processes involved in the operation of a nuclear power plant by a more meaningful learning, involving interactive and team working experience.

The simulator provides the plant responses using TRAC as the software package. Very illustrative screens display all the plant systems, and allow to act directly on the system components. Alarm control panels, similar to the ones existing in the control room of a nuclear power plant, are also available to alert users to potential equipment problems or unusual conditions. The components and systems of the whole power plant are simulated, this includes the nuclear reactor, the pressurized vessel, the primary and secondary loops, the turbine, the condenser, the fluids systems, the instrumentation and control components, and the electrical systems, as well as the emergency systems that are automatic started when needed.

The simulator provides the real plant responses during normal operation, and simulates several maneuvers, a series of malfunctions, and operational transients, and it also allows the training in emergency operation procedures. With the simulation of these situations the student is trained in the plant behavior, and in the nuclear and thermohydraulics phenomenology in the nuclear reactor and in the components of the whole plant.

Standard operational situations to run by the students are: Normal operation in nominal power; Nuclear power variations and turbine demand follow; Plant start-up from Cold-Zero-Power to Full-Power; and Plant down from Full-Power to Cold-Zero-Power, and evolution during the Zero-Power period.

For the simulation of hypothetical accidents, best-estimate and realistic codes are used. The evolution is run in real time, and the students take conscience of the time and the risk of these potential situations, and the high reliability needed in order to limit the global risk. The accidental and complex situations run by the students are: Loss of coolant accident (LOCA), Steam generator tubes leakage or rupture, stop of the main pump rotor, transients with failure of the protection system and the reactor scram, Pressurizer fault, Main steam line break (MSLB) in/out the Containment building, Anticipated Transients without Scram (ATWS), etc.

3.2 Neutron dosimetry laboratory

The neutron measurements laboratory of NED-UPM has two neutron sources (^{241}Am-Be with 77 and 111 GBq), a cylindrical water cask (0,9m diameter) for irradiation with thermalized neutron, and a precision bench for irradiations in air by means of a fully automated pneumatic device for storage, transport and positioning of the source and measuring instruments. The installation has a Bonner spheres spectrometer with a small ^{6}LiI(Eu) scintillation detector, four shadow cones (made of iron and polyethylene) and a Berthold LB6411 ambient dosimeter.

By using detailed Monte Carlo methods with MCNP code, several studies have been carried out to characterize the neutron fields in the laboratory in a set of reference points when the ^{241}Am-Be source is situated in irradiation position 3 m over the floor and 4.5 m far from the nearest walls. It The ambient dose equivalent obtained by calculations has been also compared with that obtained from the spectrometric measurements and directly with the dosimeter measurements.

3.3 Experimental sputtering set-up for coating deposition.

The research company Nano4Energy is specialized on development, design and commissioning setups for sputtering deposition. In particular, this company develops coating solutions by using High Impulse Magnetron Sputtering (HIPIMS), DC and RF sputtering techniques. The company is commissioning a pre-industrial process at NED-UPM for the development of sputtering deposition of thin film for different purpose (photovoltaic cells, optical coatings, plasma facing components…).

That installation will be used with adequate modifications for diagnosis and irradiation of advanced materials in the same conditions that those at the first wall of the chamber of Laser Fusion Reactors. A similar facility already used at the Spanish Research Council CSIC will be now upgraded for higher voltage and stronger conditions. The installation will also be used for research activities for the Programme students. Moreover, because of the versatility of the facility and the experience in coating deposition of NED-UPM members, this setup is also intended to be used for the deposition of nanostructured-based materials (high radiation resistant).

4. International Masters Programs

NED-UPM is involved in several international programs:

- European Master of Science in Nuclear Engineering
- Erasmus-Mundus Nuclear Fusion Science and Technology

- Erasmus Curricula in Plasma Physics and Fusion Technology (PLAPA, New program)

Our University is involved and participates in several Education and Training Platforms, at national level is part of the CEIDEN technological Platform, at European level in the Sustainable Nuclear Energy Technology Platform (SNE-TP), and the European Nuclear Education Network (ENEN) association, both promoted by the European Commission. We also participate in the National Platform for Fusion Technology, and in the recently started National Ministerial Programme INDUCIENCIA that aims to join industry with universities and research institutions; in both cases the participation is not only for research and development, but also with intensive subprograms for education and training. Also the University has participated in programs of the World Nuclear University (WNU), and the Frederic Joliot & Otto Hahn Summer School (UE).

5. Research Programs

NED-UPM has agreements with several foreign universities and companies in the nuclear field, being some of them cooperative partners in European research projects. Our Doctoral students may take advantage of that, doing the PhD research work in the projects, also NED-UPM supports the invitation of relevant foreign professors to teach advanced seminars to our students. New Programmes are also established with Institutions in Chile, Argentina, Japan and China.

The different research areas carried out in NED-UPM cover the main topics in Nuclear Engineering field, supported by the National Research Programs, the Nuclear Safety Council, the National Radioactive Waste Management Company ENRESA, the nuclear power plants, or international organizations as EURATOM, STFC RAL in the UK, CEA in France, CERN, LLNL and LANL in USA, Japanese Science and Technology through Bilateral Agreement (ILE Osaka and Graduate Photonic Institute).

- Fission Reactor Physics
  - SEANAP System for PWR reactor cores design and analysis with original methodology.
  - PWR operation surveillance.
  - Nuclear data needs, processing and development of tools
  - Burnup credit criticality safety
  - Sensitivity and uncertainty analysis for nuclear criticality safety and burnup calculations

- Nuclear Safety
  -
  - Analysis of Severe Accidents in LWR
  - Integrated Safety Assessment and Probabilistic Safety Assessment for NPP

- Radiological protection
  - Dosimetry and neutron metrology
  - Environmental, radiological and economic impact of nuclear energy
  - Decision support systems for Nuclear Emergencies and post-accident management

- Nuclear Fusion
  - Development of computational models for target physics in Inertial Confinement Fusion
  - Design and analysis of experiments under the EU support, for X-ray lasers and for ICF.
  - Fusion reactors study and design (both engineering/experimental and Power Plants)
  - Development of computational models for the analysis of activation and material damage by irradiation.
  - Experiments in the area of Materials Irradiation and NanoMaterials development in collaboration with other research centers

- Fluid Dynamics
- – Development of a 2D fluid dynamic model with radiation transport using advanced techniques.
- – Development of new algorithms for considering in the state-of-art codes for engineering design new data bank and modifications to incorporate new fluids, key in new reactors.

- Materials
- – Development of New Advanced Materials with new nanostructures to support very high irradiation of Ions, X-rays, Gammas and Neutrons. Structural and Functional materials such as optical lenses using both Multiscale Modeling and Experiments.
- – Damage in nuclear reactors vessels
- – Separation and Transmutation of radioactive waste.

- New Sources of Radiation (by Lasers and Accelerators)
- – Design of New Facilities for very advanced Irradiation in extreme high fluxes of Particles and Radiation and potentially new methods for Medical and Industrial Applications, and Material and Biological Diagnosis.
- – Laser Generated Ions, Positron and Neutrons
- – Spallation Sources

6. Conclusions

The introduction of the current computational methodologies/codes for nuclear engineering in our programme covers a difficult gap between nuclear reactor theory and simulations. For students, the understanding in a comprehensive way of these codes is an important value in simulation, design and advanced analysis both in the research activities and in the professional work.

The Interactive Graphical Simulator has been proven to be an optimal tool to transfer the knowledge of the physical phenomena that are involved in the nuclear power plants, from the nuclear reactor to the whole set of systems and equipment on a nuclear power plant. The experimental set-ups for neutron research and for coating fabrication offer new opportunities for training and research activities. All of them are relevant tools for motivation of the students, and to complete the theoretical lessons. They also follow the tendency recommended for the European Space for higher Education (Bologna) adapted studies, help to increase the hands-on work of the student, and allows them to experience the work inside a team, in practical and real installations.